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(54) **PLASMA SWITCHED ARRAY ANTENNA**

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H01Q 3/24	(2006.01)
H01Q 15/00	(2006.01)
H01Q 21/22	(2006.01)
H01Q 21/00	(2006.01)

(52) **U.S. Cl.**
CPC ***H01Q 3/24*** (2013.01); ***H01Q 15/0033*** (2013.01); ***H01Q 21/0031*** (2013.01); ***H01Q 21/22*** (2013.01)

(58) **Field of Classification Search**
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USPC 343/374, 876, 785, 701, 753, 904
See application file for complete search history.

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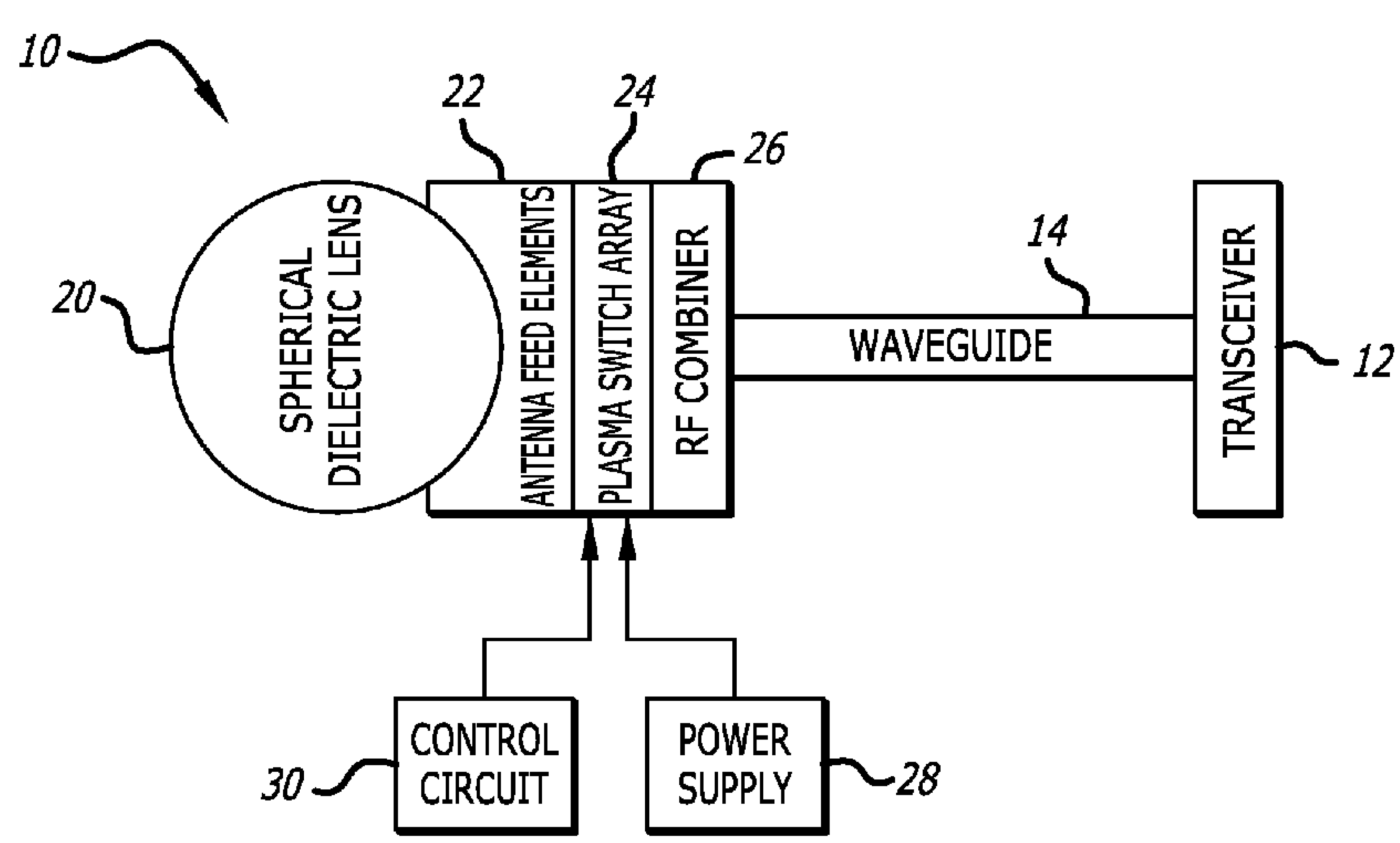
(57) **ABSTRACT**

A reconfigurable antenna comprises a plurality of antenna feed elements, a plurality of plasma switches respectively associated with the antenna feed elements, and control circuitry for independently operating the plasma switches to selectively activate and deactivate the antenna feed elements. Each plasma switch may comprise a volume of inert gas, and a pair of electrodes spanning the respective volume of inert gas. The reconfigurable antenna may comprise a power supply for supplying a voltage to the pair of electrodes of each of plasma switch sufficient to ignite the respective inert gas volume into a plasma field to deactivate the respective antenna feed element. Each plasma switch may optionally be operated to attenuate each antenna feed element.

23 Claims, 8 Drawing Sheets



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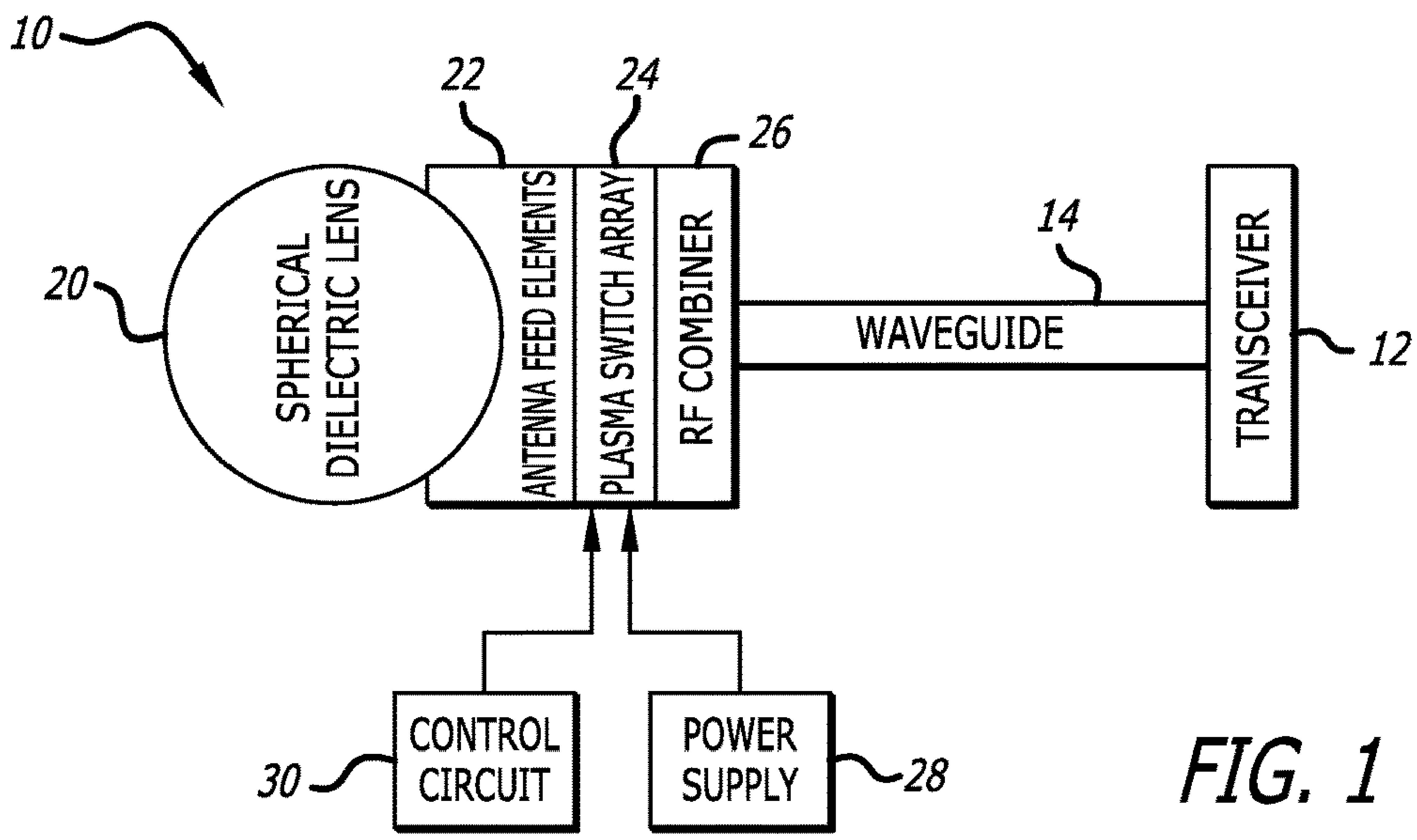

10
22
24
26
20
SPHERICAL DIELECTRIC LENS
ANTENNA FEED ELEMENTS
PLASMA SWITCH ARRAY
RF COMBINER
14
WAVEGUIDE
TRANSCEIVER
12
CONTROL CIRCUIT
30
POWER SUPPLY
28

FIG. 1

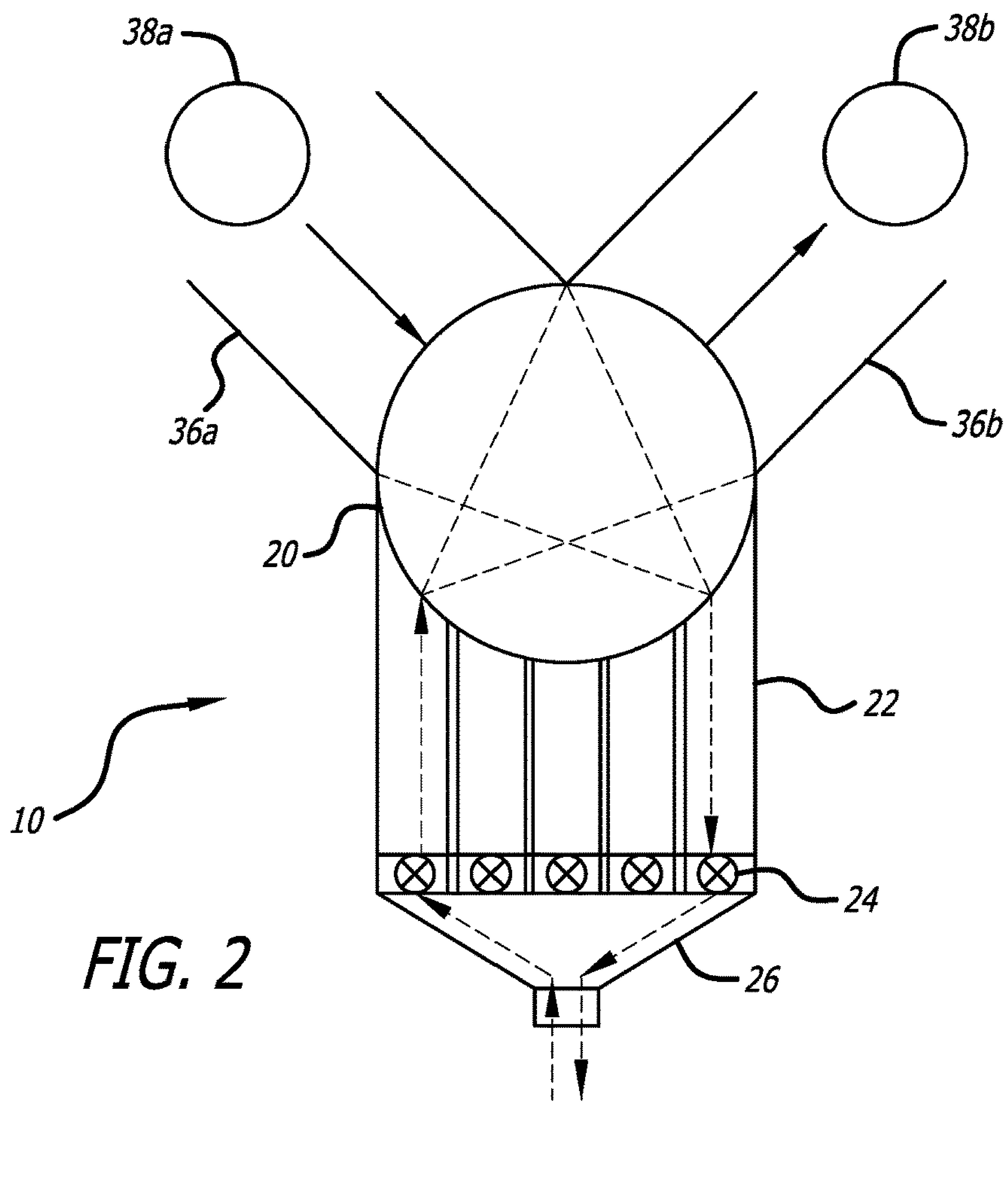

38a
38b
36a
36b
20
22
10
24
26

FIG. 2

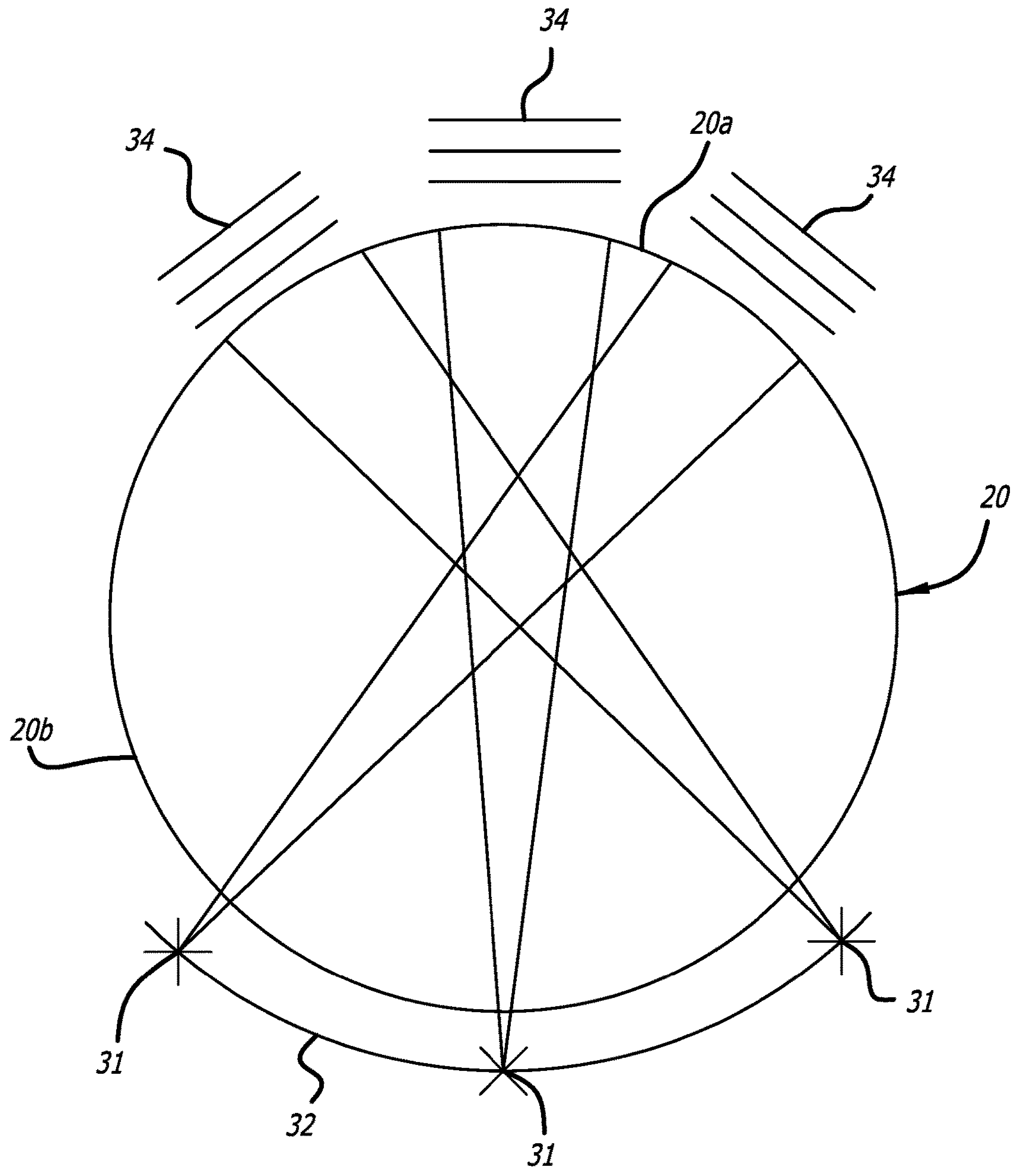


FIG. 3

FIG. 4A

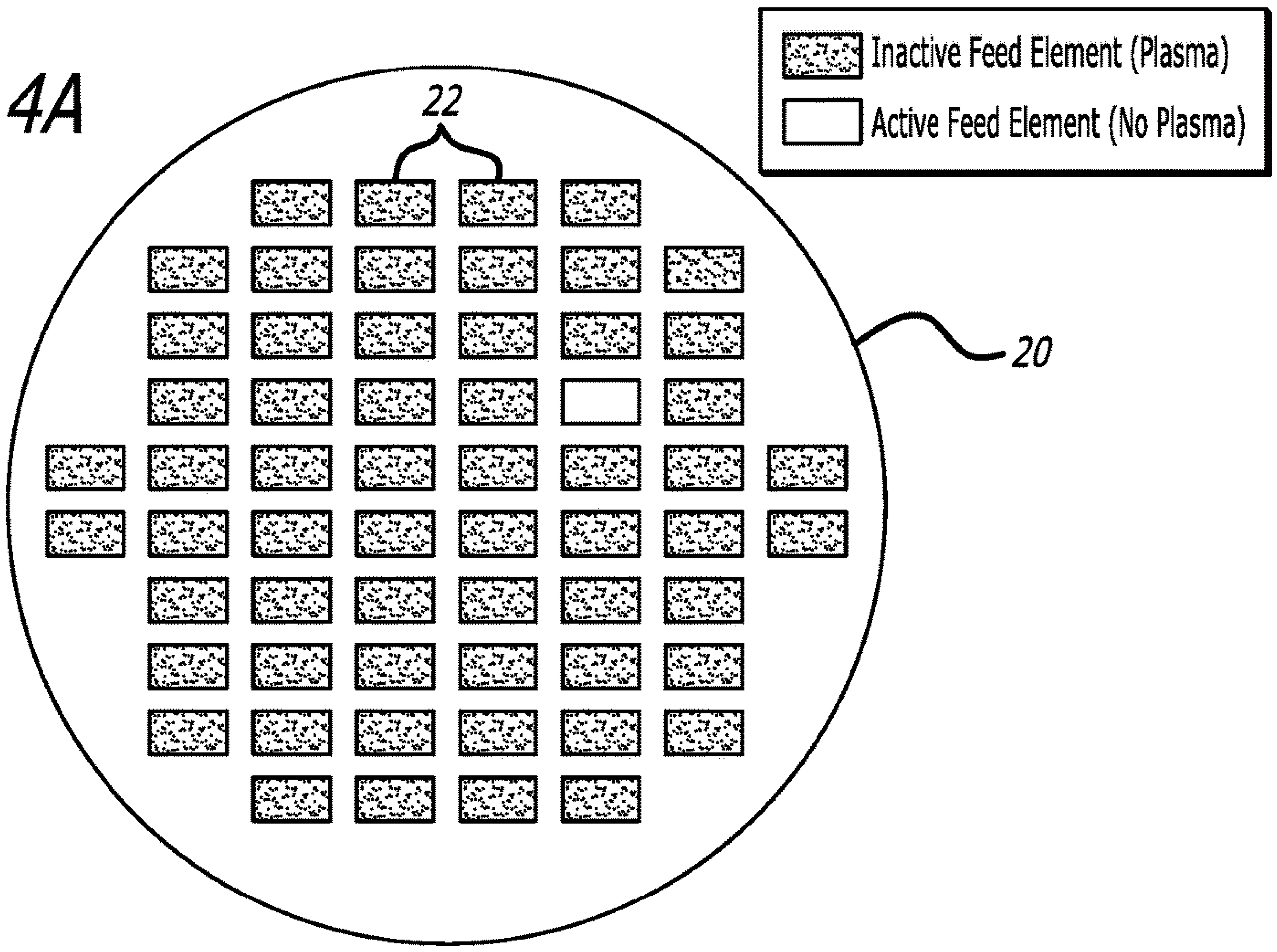

Inactive Feed Element (Plasma)
Active Feed Element (No Plasma)
22
20

FIG. 4B

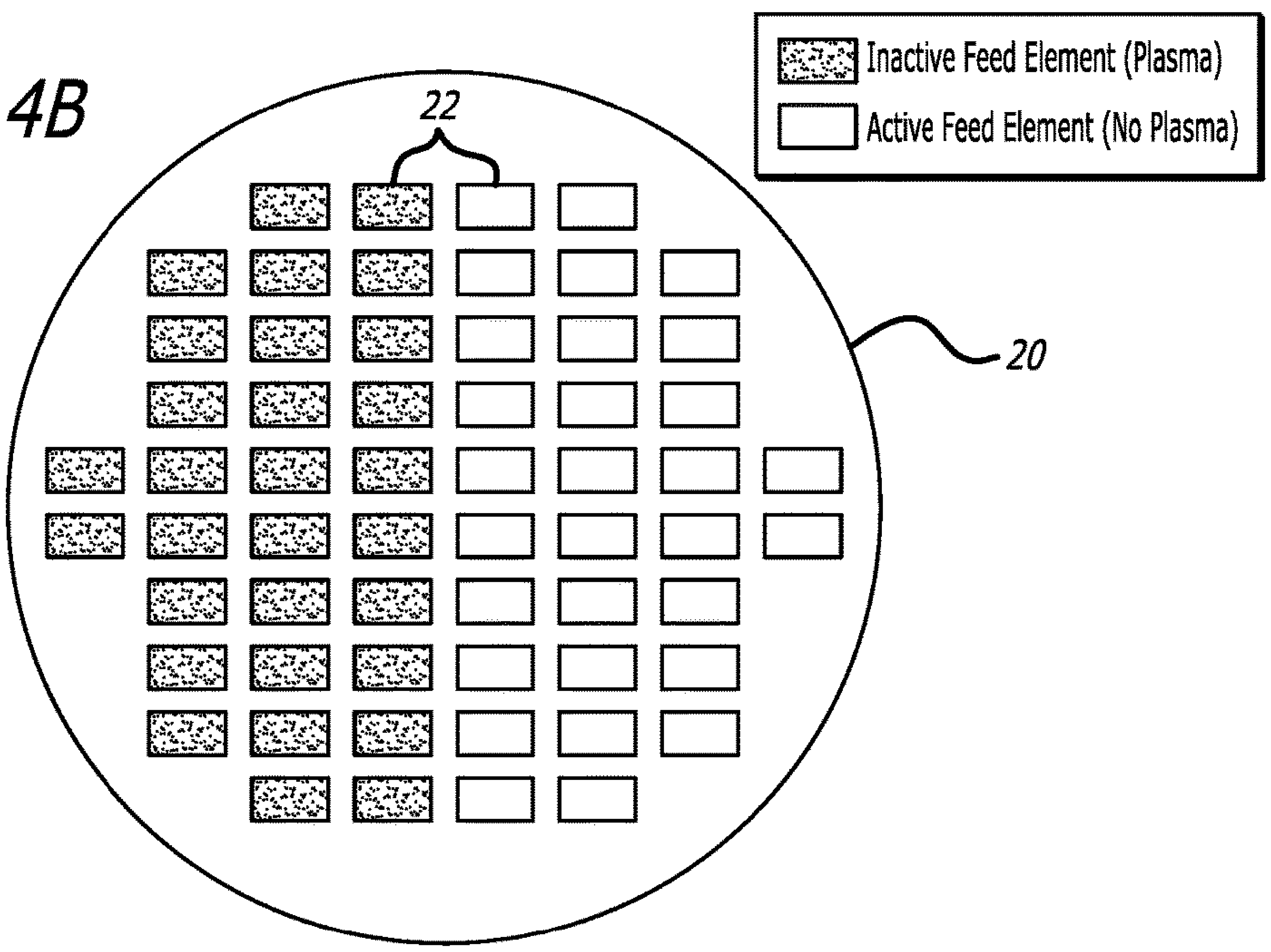

Inactive Feed Element (Plasma)
Active Feed Element (No Plasma)
22
20

FIG. 4C

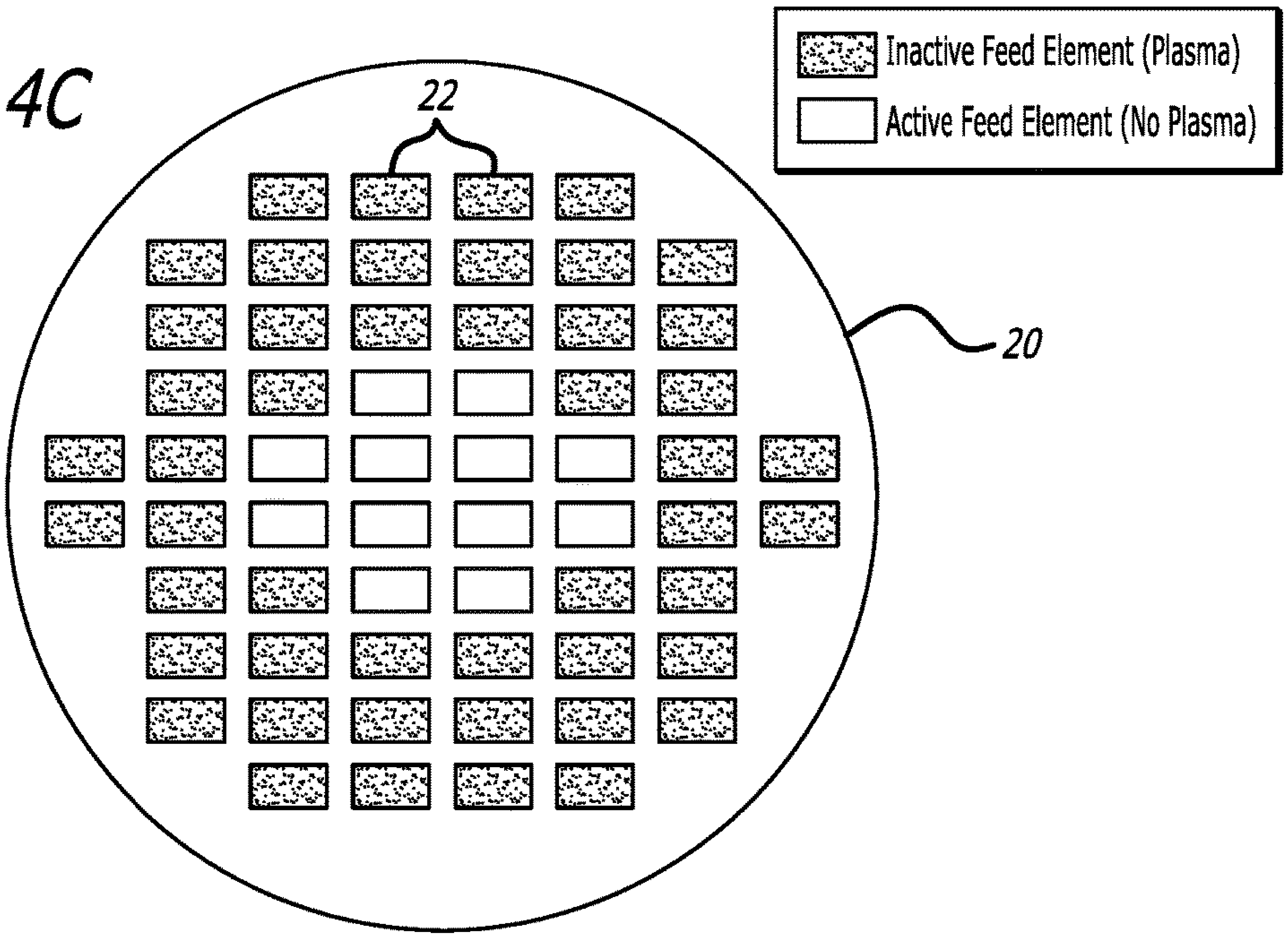

Inactive Feed Element (Plasma)
Active Feed Element (No Plasma)
22
20

FIG. 4D

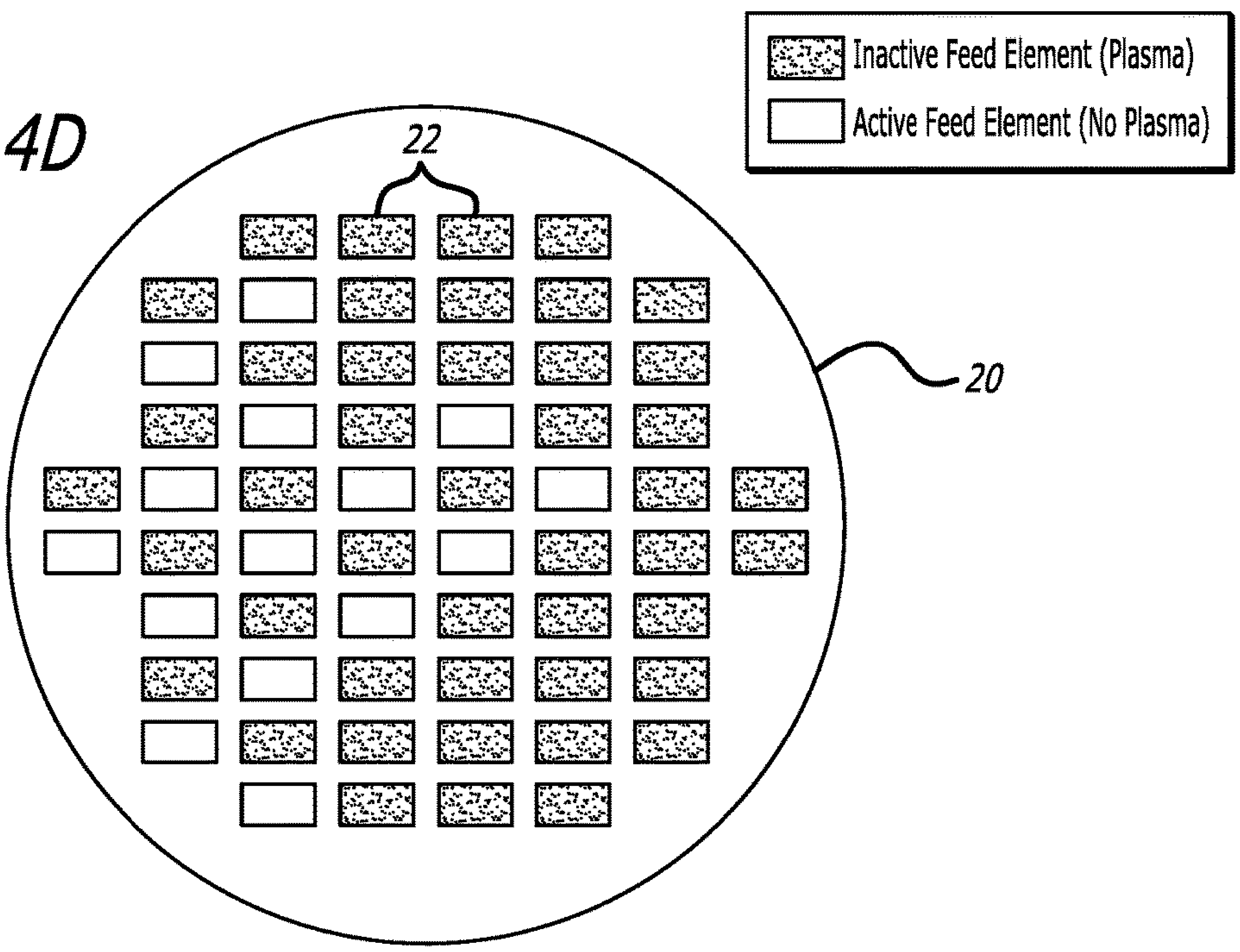
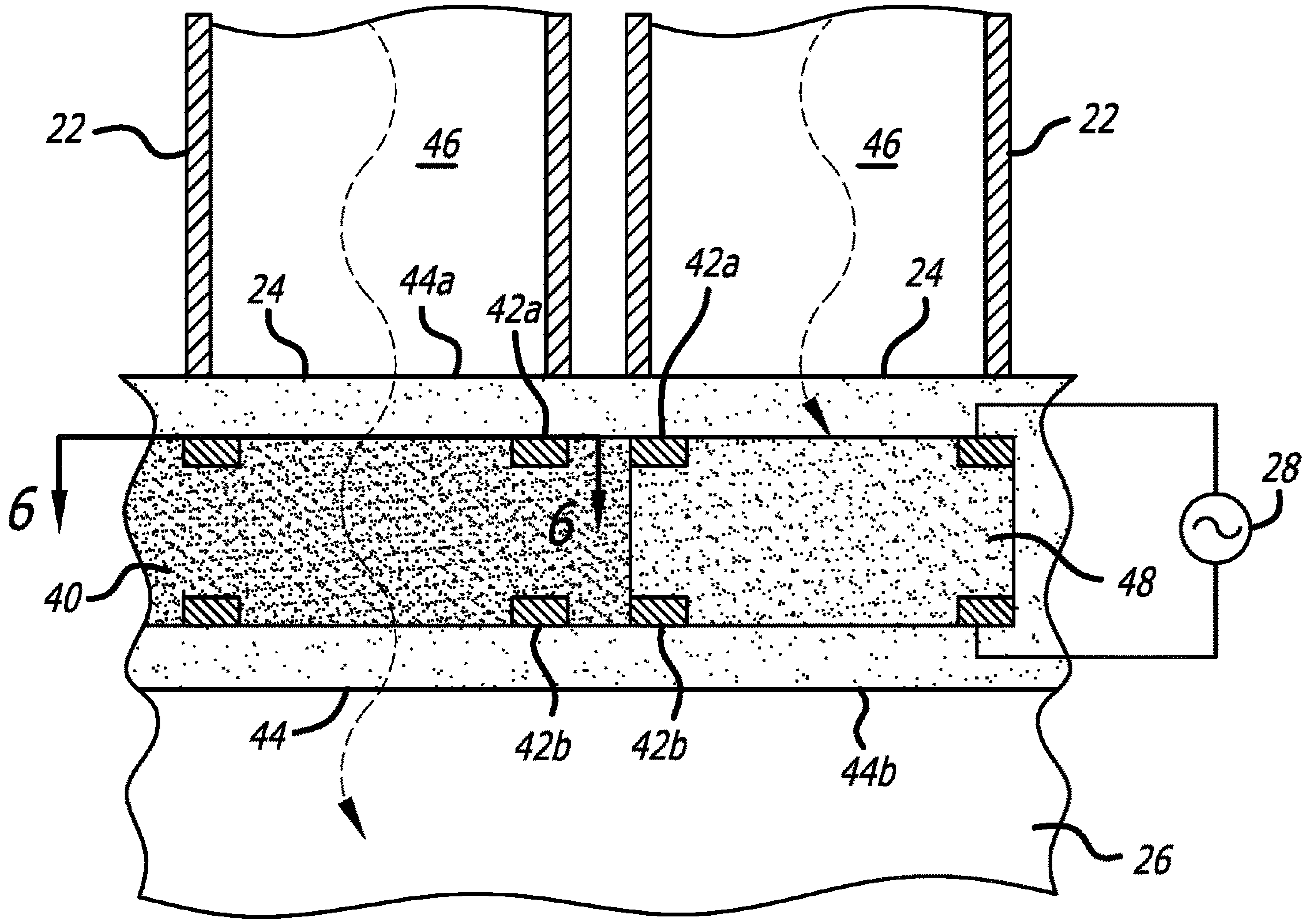

Inactive Feed Element (Plasma)
Active Feed Element (No Plasma)
22
20

FIG. 5



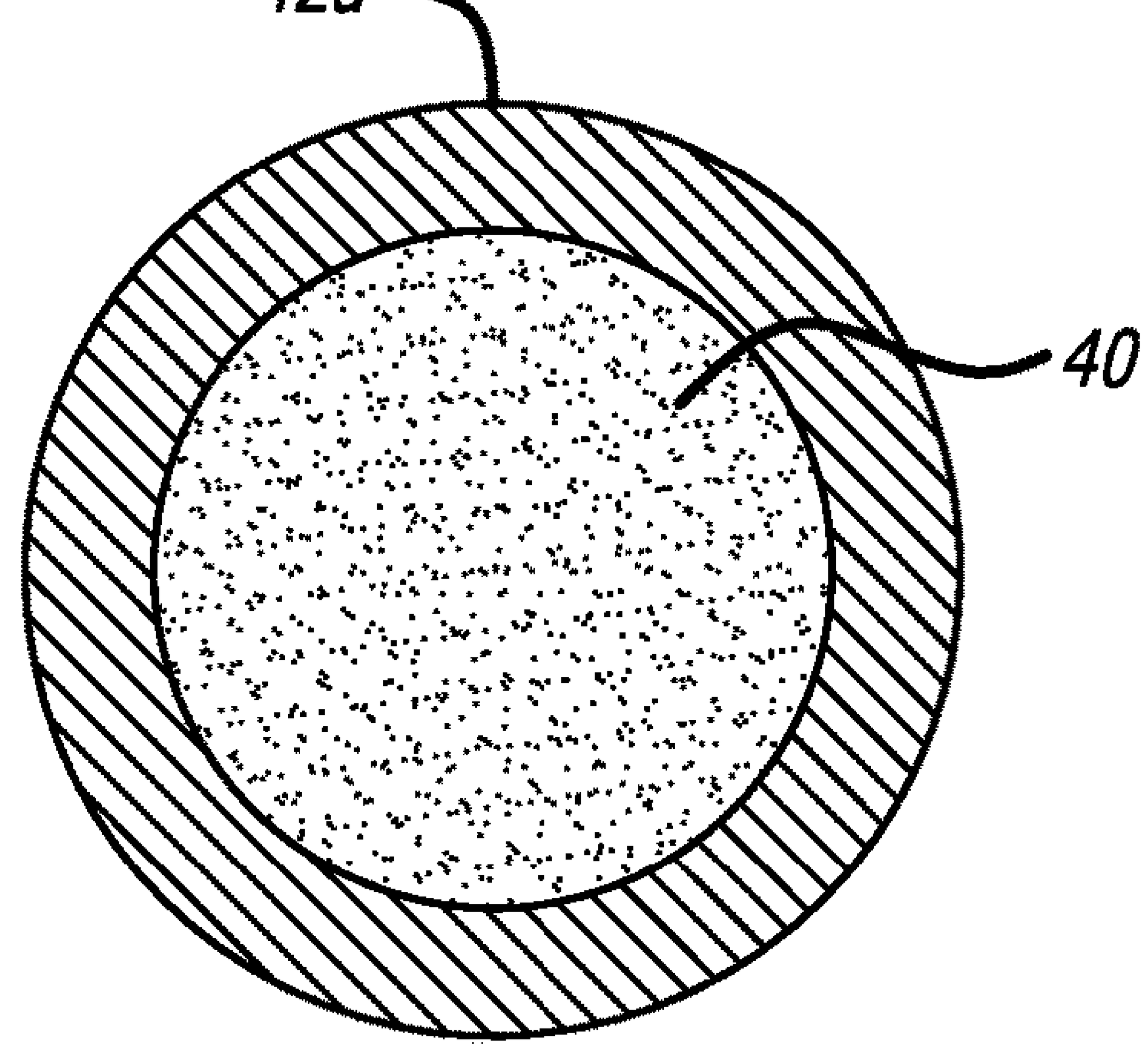
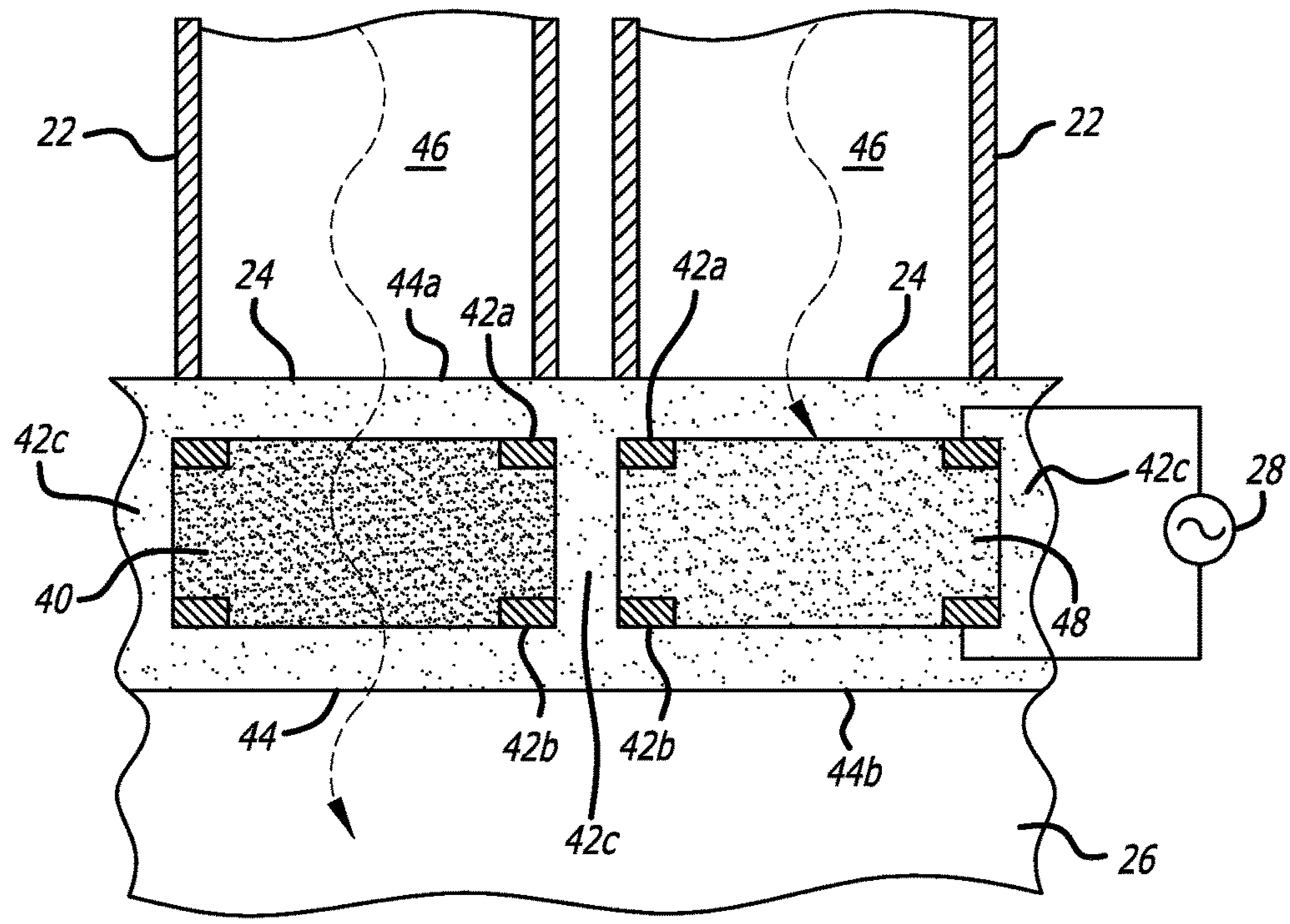


FIG. 6

FIG. 7


22
46
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24
44a
42a
42a
24
42c
42c
28
40
48
44
42b
42b
44b
42c
26

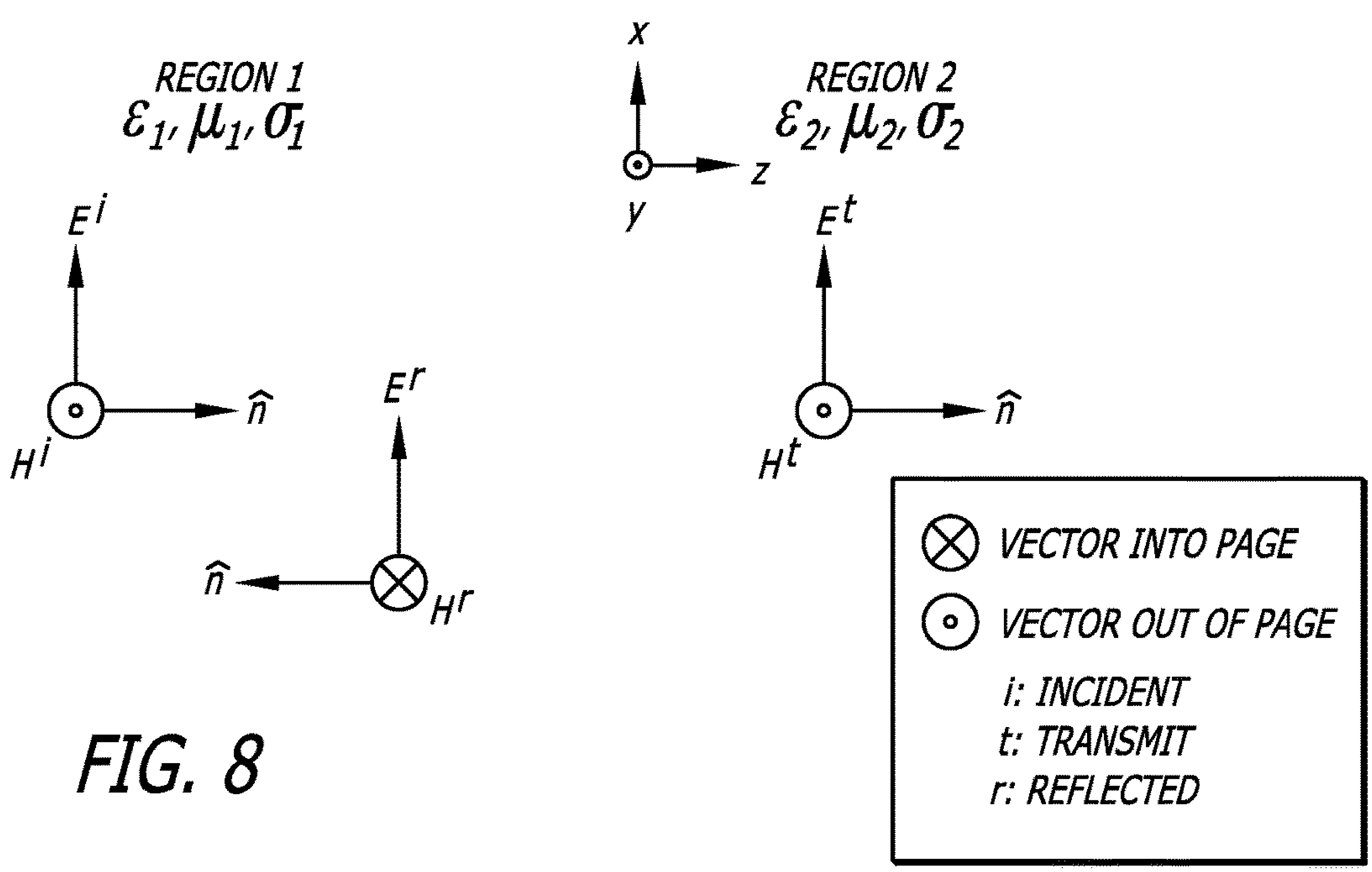

REGION 1
ε1, μ1, σ1
x
z
y
REGION 2
ε2, μ2, σ2
Ei
Et
n̂
Hi
Er
n̂
Ht
n̂
Hr
VECTOR INTO PAGE
VECTOR OUT OF PAGE
i: INCIDENT
t: TRANSMIT
r: REFLECTED

FIG. 8

FIG. 9

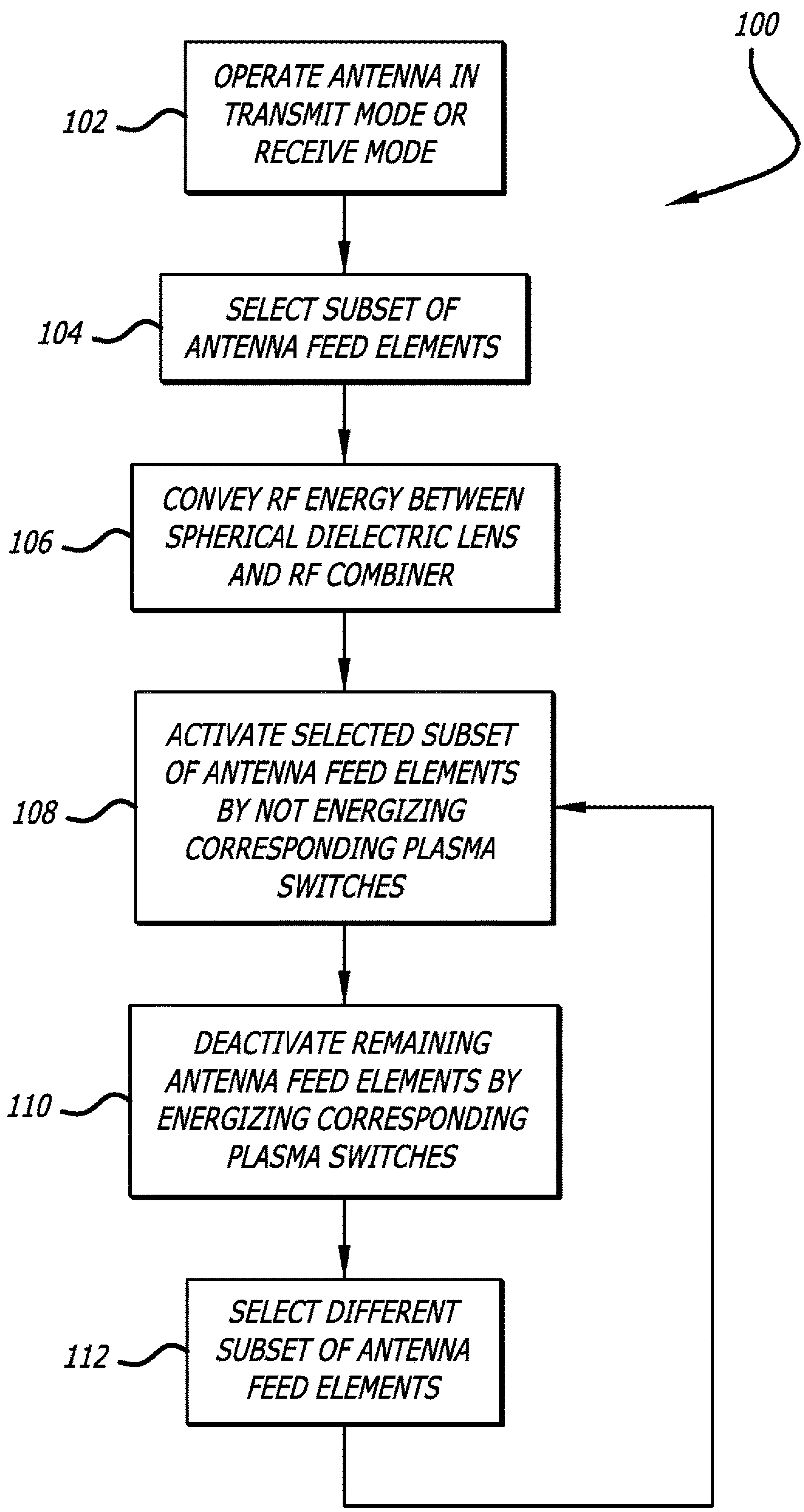
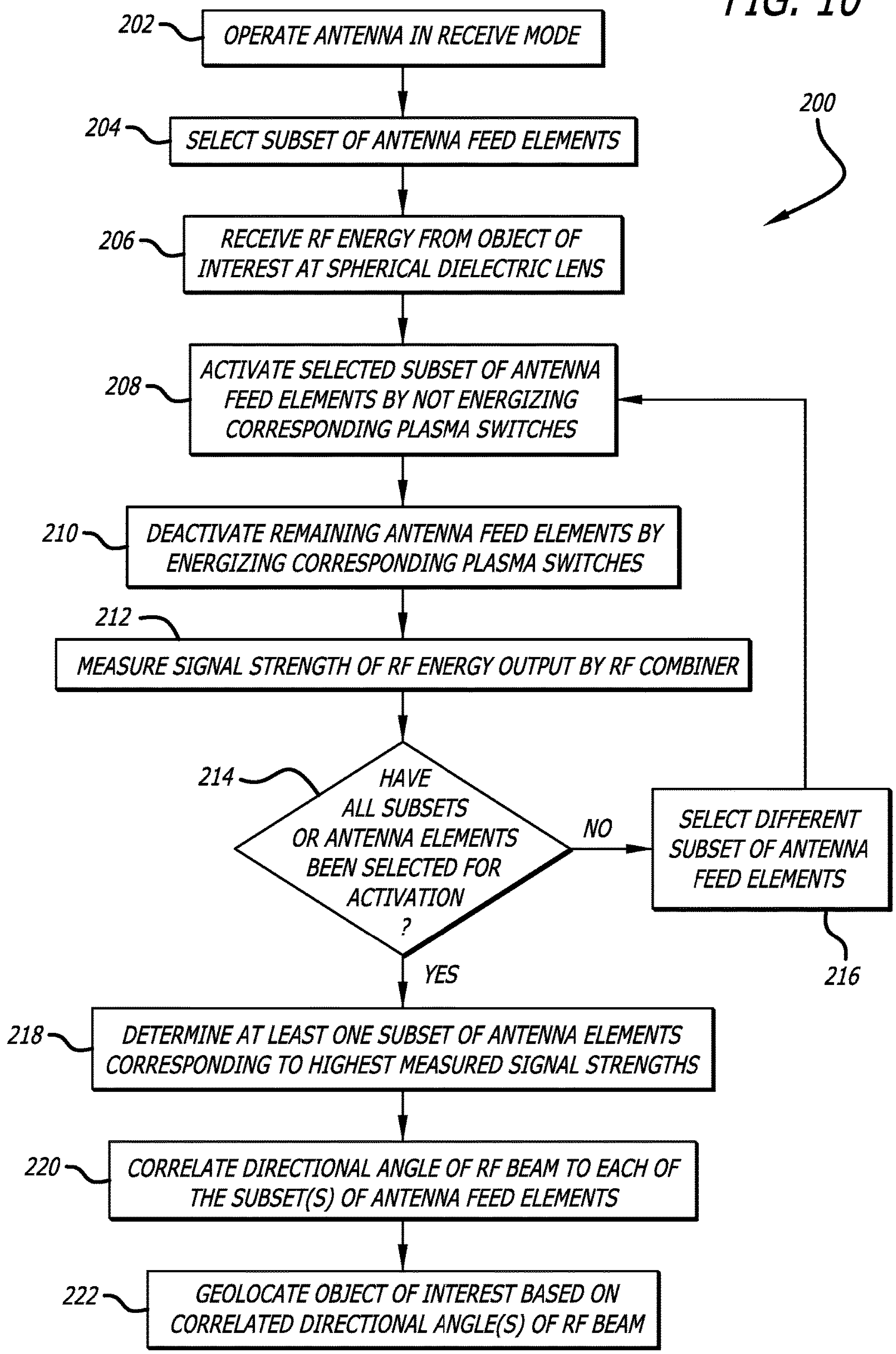

100
102
OPERATE ANTENNA IN TRANSMIT MODE OR RECEIVE MODE
104
SELECT SUBSET OF ANTENNA FEED ELEMENTS
106
CONVEY RF ENERGY BETWEEN SPHERICAL DIELECTRIC LENS AND RF COMBINER
108
ACTIVATE SELECTED SUBSET OF ANTENNA FEED ELEMENTS BY NOT ENERGIZING CORRESPONDING PLASMA SWITCHES
110
DEACTIVATE REMAINING ANTENNA FEED ELEMENTS BY ENERGIZING CORRESPONDING PLASMA SWITCHES
112
SELECT DIFFERENT SUBSET OF ANTENNA FEED ELEMENTS

FIG. 10


200
202 OPERATE ANTENNA IN RECEIVE MODE
204 SELECT SUBSET OF ANTENNA FEED ELEMENTS
206 RECEIVE RF ENERGY FROM OBJECT OF INTEREST AT SPHERICAL DIELECTRIC LENS
208 ACTIVATE SELECTED SUBSET OF ANTENNA FEED ELEMENTS BY NOT ENERGIZING CORRESPONDING PLASMA SWITCHES
210 DEACTIVATE REMAINING ANTENNA FEED ELEMENTS BY ENERGIZING CORRESPONDING PLASMA SWITCHES
212 MEASURE SIGNAL STRENGTH OF RF ENERGY OUTPUT BY RF COMBINER
214 HAVE ALL SUBSETS OR ANTENNA ELEMENTS BEEN SELECTED FOR ACTIVATION ?
NO
216 SELECT DIFFERENT SUBSET OF ANTENNA FEED ELEMENTS
YES
218 DETERMINE AT LEAST ONE SUBSET OF ANTENNA ELEMENTS CORRESPONDING TO HIGHEST MEASURED SIGNAL STRENGTHS
220 CORRELATE DIRECTIONAL ANGLE OF RF BEAM TO EACH OF THE SUBSET(S) OF ANTENNA FEED ELEMENTS
222 GEOLOCATE OBJECT OF INTEREST BASED ON CORRELATED DIRECTIONAL ANGLE(S) OF RF BEAM

PLASMA SWITCHED ARRAY ANTENNA

FIELD

The present disclosure generally relates to antennas, and more particularly, to reconfigurable antennas.

BACKGROUND

Reconfigurable antennas are antennas that can dynamically modify their frequency band, radiation pattern, polarization, and/or gain properties in a controlled and reversible manner, and have applications in the fields of cellular radio communications, geolocation, radar (ground, airplane, and unmanned airborne vehicle), smart weapons, etc. Of particular interest to the present disclosure are reconfigurable antennas that can dynamically modify its radiation pattern, e.g., by steering a radiation beam or changing the width of the beam.

Phased array antennas may be utilized to electronically steer a radiation beam through different angles, typically in the range of 60 degrees from the normal direction of the fixed physical array. Phased array antennas require that each element in the antenna array have an independent antenna element and radio frequency (RF) circuits that are aggregated to provide the overall antenna directivity, thereby creating an N-factor constraint that dictates a significant cost and power consumption penalty. Additionally, this N-factor constraint places significant circuit complexity on the antenna array, which limits production yield and operational reliability.

A simpler approach employs a mechanically articulatable antenna that includes a mechanical platform that physically moves or tilts the antenna unit to steer a radiation beam through different angles, typically in a range as much as ±90 degrees. Due to its simple electrical design, which requires only one antenna element, the N-factor constraint typically imposed on phased array antennas is avoided. However, mechanically articulatable antennas are typically slow in articulation, require moving parts that are subject to degradation, are physically very large and heavy, and are relatively expensive, thereby limiting the application of this technology.

Lens-based antenna approaches offer a viable and lower cost alternative to phased array and mechanically articulable antennas. For example, in one embodiment, multiple antenna feed elements can be placed around a spherical dielectric lens and selectively switched on and off to produce a wide field of beam coverage that avoids some of the engineering issues of phased array and mechanically articulatable antennas. However, although less technically complex than phased array antennas, reconfigurable lens-based antennas require multiple antenna feed elements and associated switches, and thus, still suffer from an N-factor constraint in terms of weight, power, size, and cost.

Of particular interest to the present disclosure are the switches used to selectively turn the antenna feed elements on and off. Various types of conventional switches that can be used for the antenna feed elements include servo-mechanical switches, ferrite switches, and pin-diode switches. Servo-mechanical switches are relatively slow, typically having switch speeds on the order of 10^{-3} seconds (or several kilohertz). Ferrite switches require a relatively large amount of power to operate. Pin-diode switches are relatively complicated and expensive. All known conventional switches, including servo-mechanical switches, ferrite switches, and pin-diode switches, require some type of

transition from the antenna feed element to a board or to a connector, thereby introducing insertion losses and additional design complexity into the reconfigurable antenna design.

There, thus, remains a need for an improved mechanism for selectively switching antenna feed elements in a reconfigurable antenna.

SUMMARY

In accordance with a first aspect of the present disclosure, a reconfigurable antenna comprises a plurality of antenna feed elements (e.g., a plurality of waveguides). In one embodiment, the antenna feed elements are circular, although the antenna feed elements may alternatively be rectangular. In one embodiment, the reconfigurable antenna further comprises a focusing element (e.g., a dielectric lens, such as a spherical dielectric lens) having a focal plane on which the antenna feed elements are located.

The reconfigurable antenna further comprises a plurality of plasma switches respectively associated with the antenna feed elements. The reconfigurable antenna may further comprise a radio frequency (RF) combiner coupled to the antenna feed elements via the respective plasma switches. In one embodiment, each of the plasma switches comprises a volume of inert gas (e.g., Neon, Xenon, Argon, or a combination thereof) and a pair of electrodes (e.g., ring electrodes) spanning the respective inert gas volume. In such case, the reconfigurable antenna may further comprise a dielectric chamber containing the inert gas volumes. This dielectric chamber may comprise side walls that isolate the respective inert gas volumes from each other, with such inert gas volumes being at a pressure less than atmospheric pressure. The dielectric chamber may comprise a top dielectric wall in which a first one of the pair of electrodes of each plasma switch is incorporated, and a bottom dielectric wall in which a second one of the pair of electrodes of each plasma switch is incorporated. The reconfigurable antenna may further comprise a power supply for supplying a voltage to the pair of electrodes of each of the plasma switches sufficient (e.g., 100V-300V DC/AC-RMS) to ignite the respective inert gas volume into a plasma field (e.g., having a plasma density greater than 10^9 free electrons per cm^3).

The reconfigurable antenna further comprises control circuitry for independently operating the plasma switches to selectively activate and deactivate the antenna feed elements. To this end, the control circuitry may be for selectively controlling the supply of the voltage from the power supply to the respective plasma switches to selectively turn the respective antenna feed elements on or off. In one embodiment, the control circuitry may be for independently operating the plasma switches to attenuate the antenna feed elements. In another embodiment, the control circuitry may be for independently operating the plasma switches to dynamically steer an RF beam. For example, the control circuitry may be for independently operating the plasma switches to selectively activate and then deactivate the respective antenna feed elements one at a time. As another example, the control circuitry may be for independently operating the plasma switches to alternately activate and then deactivate two halves of the antenna feed elements. In still another embodiment, the control circuitry is for independently operating the plasma switches to dynamically modify an aperture of a beam. In yet another embodiment, the control circuitry may be for independently operating the plasma switches to activate and then deactivate different group sizes of antenna feed elements.

In accordance with a second aspect of the present disclosure, an antenna comprises at least one feed element (e.g., at least one waveguide). In one embodiment, the antenna feed element(s) are circular, although the antenna feed element(s) may alternatively be rectangular. In one embodiment, the reconfigurable antenna further comprises a focusing element (e.g., a dielectric lens, such as a spherical dielectric lens) having a focal plane on which the antenna feed elements(s) are located.

The antenna further comprises at least one plasma switch respectively associated with the antenna feed element(s). If there are multiple antenna feed elements, the reconfigurable antenna may further comprise a radio frequency (RF) combiner coupled to the antenna feed elements via the respective plasma switches. Each of the plasma switch(es) comprises a volume of inert gas (e.g., Neon, Xenon, Argon, or a combination thereof), and a pair of electrodes spanning the respective volume of inert gas. In such case, the reconfigurable antenna may further comprise a dielectric chamber containing the inert gas volume(s). In the case of multiple plasma switches, this dielectric chamber may comprise side walls that isolate the respective inert gas volumes from each other, with such inert gas volumes being at a pressure less than atmospheric pressure. The dielectric chamber may comprise a top dielectric wall in which a first one of the pair of electrodes of each plasma switch is incorporated, and a bottom dielectric wall in which a second one of the pair of electrodes of each plasma switch is incorporated.

The antenna further comprises a power supply is for supplying a voltage to the pair of electrodes of each of the plasma switch(es) sufficient to ignite the respective inert gas volume into a plasma field. In one embodiment, the plasma field is capable of deactivating the respective antenna feed element (e.g., if the plasma density is greater than 10^9 free electrons per cm^3). In another embodiment, the plasma field is capable of attenuating the respective antenna feed element (e.g., if the plasma density is between 10^7-10^9 free electrons per cm^3).

In accordance with a third aspect of the present disclosure, an antenna comprises at least one feed element (e.g., at least one waveguide). In one embodiment, the antenna feed element(s) are circular, although the antenna feed element(s) may alternatively be rectangular. In one embodiment, the reconfigurable antenna further comprises a focusing element (e.g., a dielectric lens, such as a spherical dielectric lens) having a focal plane on which the antenna feed elements(s) are located.

The antenna further comprises at least one plasma switch respectively associated with the antenna feed element(s), and control circuitry for operating each of the plasma switch(es) to attenuate each of the antenna feed element(s). If there are multiple antenna feed elements, the reconfigurable antenna may further comprise a radio frequency (RF) combiner coupled to the antenna feed elements via the respective plasma switches. Each of the plasma switch(es) comprises a volume of inert gas (e.g., Neon, Xenon, Argon, or a combination thereof), and a pair of electrodes spanning the respective volume of inert gas. In such case, the reconfigurable antenna may further comprise a dielectric chamber containing the inert gas volume(s).

In the case of multiple plasma switches, this dielectric chamber may comprise side walls that isolate the respective inert gas volumes from each other, with such inert gas volumes being at a pressure less than atmospheric pressure. The dielectric chamber may comprise a top dielectric wall in which a first one of the pair of electrodes of each plasma switch is incorporated, and a bottom dielectric wall in which a second one of the pair of electrodes of each plasma switch is incorporated. The antenna may further comprise a power supply for supplying a voltage to the pair of electrodes of each of the plasma switches sufficient to ignite the respective inert gas volume into a plasma field (e.g., having a plasma density between 10^7-10^9 free electrons per cm^3).

In accordance with a fourth aspect of the present disclosure, a radio frequency (RF) system comprise any of the antennas described above, and transmit and/or receive componentry coupled to the antenna feed element(s) via the respective plasma switch(es).

In accordance with a fifth aspect of the present disclosure, a method of operating an antenna comprising a focusing element having a focal plane, a plurality of antenna feed elements (e.g., waveguides) located on the focal plane, a plurality of plasma switches respectively associated with the antenna feed elements, and a radio frequency (RF) combiner coupled to the antenna feed elements via the plasma switches, is provided. In one embodiment, the antenna feed elements are circular, although the antenna feed elements may alternatively be rectangular. In one embodiment, the antenna further comprises a focusing element (e.g., a dielectric lens, such as a spherical dielectric lens) having a focal plane on which the antenna feed elements are located.

The method comprises (a) conveying RF energy between the focusing element and the RF combiner, (b) selecting a subset of the antenna feed elements (which may be a single antenna feed element), (c) independently operating the plasma switches to activate the subset of the antenna feed elements, thereby passing the RF energy through the corresponding subset of the plasma switches, and to deactivate remaining ones of the antenna feed elements, thereby blocking the RF energy through the corresponding remaining ones of the plasma switches, such that the antenna generates at least one RF beam having a characteristic, (d) selecting a different subset of the antenna feed elements, and (e) repeating step (c) with the different subset of antenna feed elements, such that the characteristic of the RF beam(s) is modified. As one example, the modified characteristic may be a directional angle of the RF beam(s). As another example, the modified characteristic may be an aperture of the RF beam(s). In still another example, the modified characteristic is a group size of the RF beam(s).

In one embodiment, each plasma switch may comprise a volume of inert gas (e.g., Neon, Xenon, Argon, or a combination thereof), in which case, operating the plasma switches to activate the subset of the antenna feed elements may comprise not applying an electric field across each inert gas volume of the subset of plasma switches, thereby passing the RF energy through the subset of plasma switches, and applying an electric field across each inert gas volume of the remaining ones of the plasma switches to ignite the each inert gas volume into a respective plasma field (e.g., one having a plasma density greater than 10^9 free electrons per cm^3), thereby blocking the RF energy through the remaining ones of the plasma switches.

In accordance with a sixth aspect of the present disclosure, a method of geolocating an object of interest using an antenna comprising a focusing element having a focal plane, a plurality of antenna feed elements located on the focal plane, a plurality of plasma switches respectively associated with the antenna feed elements, and a radio frequency (RF) combiner coupled to the antenna feed elements via the plasma switches, is provided. In one embodiment, the antenna feed elements are circular, although the antenna feed elements may alternatively be rectangular. In one embodiment, the antenna further comprises a focusing element (e.g., a dielectric lens, such as a spherical dielectric lens) having a focal plane on which the antenna feed elements are located.

The method comprises (a) receiving RF energy from the object of interest at the focusing element, (b) selecting a subset of the antenna feed elements (which may be a single antenna feed element), (c) independently operating the plasma switches to activate the subset of the antenna feed elements, thereby passing the RF energy from the subset of antenna feed elements to the RF combiner, and to deactivate remaining ones of the antenna feed elements, thereby blocking the RF energy from the remaining antenna feed elements to the RF combiner, such that an RF beam having a directional angle from the focusing element is generated, (d) measuring a signal strength of the RF energy output by the RF combiner, (e) selecting a different subset of the antenna feed elements, (f) repeating steps (c)-(d) for the different subset of antenna feed elements, and (g) geolocating the object of interest based on the measured signal strength corresponding to at least one of the selected subsets of antenna feed elements. Steps (e) and (f) may be repeated until all possible subsets of antenna feed elements have been selected and activated.

In one embodiment, geolocating the object of interest comprises determining at least one subset of antenna feed elements corresponding to at least one of the highest measured signal strengths, correlating the directional angle of the RF beam to each of the subset(s) of antenna feed elements, and geolocating the object of interest based on the correlated directional angle(s) of the RF beam. If only one subset of antenna feed elements corresponding to the highest measured signal strength is determined, the directional angle of the RF beam may be correlated to the only one subset of antenna feed elements, and the object of interest may be geolocated by identifying the directional angle of the RF beam as the location of the object of interest. If multiple subsets of antenna feed elements corresponding to the highest measured signal strengths are determined, the directional angles of the RF beam may be correlated to the multiple subsets of antenna feed elements, and the object of interest may be geolocated by computing an interpolated directional angle from the directional angles of the RF beam based on the corresponding highest measured signal strengths, and identifying the interpolated angle of the RF beam as the location of the object of interest.

In another embodiment, each plasma switch may comprise a volume of inert gas (e.g., Neon, Xenon, Argon, or a combination thereof), in which case, operating the plasma switches to activate the subset of the antenna feed elements may comprise not applying an electric field across each inert gas volume of the subset of plasma switches, thereby passing the RF energy through the subset of plasma switches, and applying an electric field across each inert gas volume of the remaining ones of the plasma switches to ignite the each inert gas volume into a respective plasma field (e.g., one having a plasma density greater than 10^9 free electrons per cm^3), thereby blocking the RF energy through the remaining ones of the plasma switches.

Other and further aspects and features of the disclosure will be evident from reading the following detailed description of the presented embodiments, which are intended to illustrate, not limit, the disclosure.

BRIEF DESCRIPTION OF DRAWINGS

The drawings illustrate the design and utility of the presented embodiments of the present disclosure, in which similar elements are referred to by common reference numerals. In order to better appreciate how the above-recited and other advantages and objects of the present disclosure are obtained, a more particular description of the present disclosure briefly described above will be rendered by reference to specific embodiments thereof, which are illustrated in the accompanying drawings. Understanding that these drawings depict only typical embodiments of the disclosure and are not therefore to be considered limiting of its scope, the disclosure will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

FIG. **1** is a block diagram of a radio frequency (RF) system constructed in accordance with one embodiment of the present disclosure;

FIG. **2** is a plan view of a reconfigurable antenna used in the RF system of FIG. **1**;

FIG. **3** is a plan view of a spherical dielectric lens used in the reconfigurable antenna of FIG. **2**;

FIG. **4***a* is a plan view of an array of antenna feed elements used in the reconfigurable antenna of FIG. **2**, particularly showing one configuration of activated antenna feed elements;

FIG. **4***b* is a plan view of an array of antenna feed elements used in the reconfigurable antenna of FIG. **2**, particularly showing another configuration of activated antenna feed elements;

FIG. **4***c* is a plan view of an array of antenna feed elements used in the reconfigurable antenna of FIG. **2**, particularly showing still another configuration of activated antenna feed elements;

FIG. **4***d* is a plan view of an array of antenna feed elements used in the reconfigurable antenna of FIG. **2**, particularly showing yet another configuration of activated antenna feed elements;

FIG. **5** is a cross-sectional view of one embodiment of plasma switches used in the reconfigurable antenna of FIG. **2**;

FIG. **6** is a cross-sectional view of a plasma switch of FIG. **5**, taken along the line **6**-**6**;

FIG. **7** is a cross-sectional view of another embodiment of plasma switches used in the reconfigurable antenna of FIG. **2**;

FIG. **8** is a plan view of an electromagnetic wave transmitted through and reflected from an interface between two media;

FIG. **9** is a flow diagram illustrating one method of operating the reconfigurable antenna of FIG. **2** to dynamically generate RF beams with differing characteristics; and

FIG. **10** is a flow diagram illustrating one method of operating the reconfigurable antenna of FIG. **2** to geolocate an object of interest.

DETAILED DESCRIPTION

Referring to FIGS. **1**-**3**, a reconfigurable antenna **10** constructed in accordance with one embodiment of the present disclosure will now be described. In a conventional manner, the reconfigurable antenna **10** is coupled to transmit and/or receive componentry in the form of a transceiver **12** that transmits and/or receives RF signals to and from the reconfigurable antenna **10** via a waveguide **14**. The reconfigurable antenna **10**, transceiver **12**, and waveguide **14** form at least a portion of an RF system, such as an RF communications system or geolocation system. In the illustrated embodiment, the reconfigurable antenna **10** is mounted to the structural body of a communications platform, such as a building (e.g., a tracking station) or spacecraft (e.g., a communications satellite).

The reconfigurable antenna **10** comprises an RF focusing element **20**, which in the illustrated embodiment, takes the form of a dielectric lens, and in particular, a spherical dielectric lens. In other embodiments, the RF focusing element **20** may take the form of flat lens, e.g., a bi-convex, a plano-convex lens, or a gradient-index (GRIN) lens. The spherical dielectric lens **20** is composed of a dielectric material having a suitable dielectric constant and loss tangent, such as polytetrafluoroethylene or polycarbonate. As best shown in FIG. **3**, the spherical dielectric lens **20** exhibits the beneficial property of uniformity across its hemisphere **20***a*, so that RF plane waves **34** that are incident on this hemisphere **20***a* from respective particular directional arrival angles are predictably focused at corresponding points **31** along a spherical focal plane **32** adjacent the opposite hemisphere **20***b* of the spherical dielectric lens **20**, and conversely, a RF energy emitted from points **31** along the focal plane **32** that are incident on the opposite hemisphere **20***b* predictably exits the hemisphere **20***a* as RF plane waves **34** at corresponding directional departure angles. As can be appreciated from the following discussion, the use of a spherical dielectric lens **20**, as opposed to a phased antenna array, allows the use of a single waveguide **14** for routing RF signals between the reconfigurable antenna **10** and the transceiver **12**, thereby providing for a simpler antenna design, while still allowing beam steering or beam aperture modification.

The reconfigurable antenna **10** further comprises an array of switchably selectable antenna feed elements **22**, the apertures of which are located at selected points **31** around the focal plane **32** of the spherical dielectric lens **20**. In the illustrated embodiment, each antenna feed element **22** takes the form of a waveguide. The focal plane **32** may be coincident with the surface of the spherical dielectric lens **20**, such that the antenna feed elements **22** may be bonded directly to the surface of the spherical dielectric lens **20**, although in presented embodiments, the focal plane **32** may be spatially offset from the surface of the spherical dielectric lens **20**, in which case, the antenna feed elements **22** may be likewise spatially offset from the surface of the spherical dielectric lens **20**, allowing the spherical dielectric lens **20** to be moved relative to the antenna feed elements **22** to align the apertures of the antenna feed elements **22** with the focal plane **32**.

Thus, an incoming RF beam **36***a* emitted from an object of interest **38***a* (in this case, a source of RF radiation) may be incident on the surface of the spherical dielectric lens **20** and focused on one or more of the antenna feed elements **22**. Conversely, RF energy emitted by one or more of the antenna feed elements **22** may be directed from the surface of the spherical dielectric lens **20** as an outgoing RF beam **36***b* to an object of interest **38***b*. When the reconfigurable antenna **10** is operated in a receive mode, the antenna feed elements **22** may be selectively and independently activated to allow the transceiver **12** to receive RF energy emitted by the object of interest **38***a*, and when the reconfigurable antenna **10** is operated in a transmit mode, the antenna feed elements **22** may be selectively and independently activated to allow the transceiver **12** to transmit RF energy to the object of interest **38***b*.

To this end, the reconfigurable antenna **10** further comprises an array of plasma switches **24** respectively associated with the antenna feed elements **22**, and an RF combiner **26** coupled to the antenna feed elements **22** that serves to convey RF energy between the multiple antenna feed elements **22** and the single waveguide **14** coupled to the transceiver **12**. In the illustrated embodiment, the plasma switches **24** are conveniently disposed between the respective antenna feed elements **22** and the RF combiner **26**, although in alternative embodiments, the plasma switches **24** may be located anywhere in the path of the antenna feed elements **22**.

In the illustrated embodiment, the reconfigurable antenna **10** is designed to transmit and receive circularly polarized RF energy (e.g., both left hand circularly polarized (LHCP) and right hand circularly polarized (RHCP)), although in alternative embodiments, the reconfigurable antenna **10** may be designed to transmit and receive linearly polarized RF energy (e.g., both horizontally polarized (HP) and vertically polarized (VP)). In the illustrated embodiment, the cross-sectional profile of the antenna feed elements **22**, plasma switches **24**, RF combiner **26**, and waveguide **14** are circular, although in alternative embodiments, the cross-sectional profile may be rectangular.

As briefly discussed above, the antenna feed elements **22** may be selectively activated via the plasma switches **24**. To this end, the reconfigurable antenna **10** further comprises a power supply **28** for supplying power to the plasma switches **24**, and control circuitry **30** for independently operating the plasma switches **24** to selectively activate the respective antenna feed elements **22** by selectively controlling the supply of voltage from the power supply **28** to the respective plasma switches **24**, as will be described in further detail below. In an optional embodiment, rather than turning the antenna feed element(s) **22** on or off, the control circuitry **30** may independently attenuate the antenna feed elements **22** by selectively controlling the supply of voltage form the power supply **28** to the respective plasma switches **24**.

The control circuitry **30** may be for independently operating the plasma switches **24** via the power supply **28** to dynamically steer the RF beam. In one example illustrated in FIG. **4***a*, the control circuitry **30** may independently operate the plasma switches **24** to direct the RF beam towards a small portion of the sky by activating and then deactivating only one antenna feed element **22** at a time. As another example illustrated in FIG. **4***b*, the control circuitry **30** may independently operate the plasma switches **24** to direct the RF beam towards half of the sky by activating a first contiguous half of the antenna feed elements **22** while deactivating the second contiguous half of the antenna feed elements **22**, and then activating the second contiguous half of the antenna feed elements **22** while deactivating the first contiguous half of the antenna feed elements **22**.

The control circuitry **30** may also be for independently operating the plasma switches **24** to dynamically modify an aperture of the RF beam. As one example illustrated in FIG. **4***c*, the control circuitry **30** may independently operate the plasma switches **24** to modify the aperture of the RF beam by activating different sized ellipsoidal groups of antenna feed elements **22**. The control circuitry **30** may also be for independently operating the plasma switches **24** to dynamically generate different groupings of multiple RF beams **36**. As one example illustrated in FIG. **4***d*, the control circuitry **30** may independently operate the plasma switches **24** to generate fifteen RF beams by activating fifteen corresponding antenna elements **22**.

It can be appreciated from the foregoing that the reconfigurable antenna **10** may be utilized to geolocate the object of interest **38**, and depending on the particular application, to communicate with such object of interest **38**. For example, the specific direction of arrival of the incoming RF beam **36***a*, and thus, the angular location of the object of interest **38**, may be ascertained by interrogating the antenna feed elements **22**, and in particular, by activating and deactivating selected ones of the antenna feed elements **22**, and determining the particular antenna feed element(s) **22** that receive RF energy from the object of interest **38**. The antenna feed element(s) **22** that receive the RF energy from the object of interest **38** can then be selected to communicate (either in receive mode to receive RF energy or transmit mode to transmit RF energy) with the geolocated object of interest **38**.

Referring now to FIGS. **5** and **6**, one embodiment of a plasma switch **24** will be described in further detail. Each plasma switch **24** comprises a volume of inert gas **40** disposed in a signal path between the aperture of the respective antenna feed element **22** and the RF combiner **26**, a pair of electrodes **42** spanning the inert gas volume **40**, and a dielectric chamber **44** containing the inert gas volume **40**.

In the illustrated embodiment, the inert gas volume **40** is located between the end of the antenna feed element **22** and the RF combiner **26**, although the volume of inert gas **40** may be disposed in the middle of the antenna feed element **22** if desired. The inert gas volume **40** may comprise, e.g., Neon, Xenon, or Argon, or a combination thereof to minimize corrosion of the electrodes **42**, although the inert gas volume **40** may alternatively comprise air if the electrodes **42** are not exposed to the inert gas volume **40**.

In the illustrated embodiment, both electrodes **42** are ring electrodes that are disposed around the circumference of the inner cavity of the respective antenna feed element **22** to minimize interference of RF signals propagating within the antenna feed element **22** when activated. Because in the illustrated embodiment, the cross-section of the antenna feed element **22** is circular, the ring electrode **42** will likewise be circular. However, in the case where the cross-section of the antenna feed element **22** is rectangular, the ring electrode **42** will be rectangular. In alternative embodiments, the electrodes **42** may take other forms that do not significantly interfere with the RF signal propagating through the antenna feed element **22** when activated.

The dielectric chamber **44** can be composed of any suitable dielectric material (e.g., glass) that is essentially transparent to RF energy and that is capable of containing the inert gas volume **40**. The dielectric chamber **44** comprises a top wall **44***a* (or layer) in which the top electrode **42***a* is incorporated, and a bottom wall **44***b* (or layer) in which the bottom electrode **42***b* is incorporated. The electrodes **42** may be suitably patterned onto or within the respective top and bottom dielectric walls **44**. Notably, the top wall **44***a* and bottom wall **44***b* of the dielectric chamber **44** may span the entire array of plasma switches **24**, such that a single top wall **44***a* and a single bottom wall **44***b* may be used to contain all of the inert gas volumes **40** in the array of plasma switches **24**. As illustrated in FIG. **7**, the dielectric chamber **44** may optionally comprise side walls **44***c* that isolate the respective inert gas volumes **40** for the plasma switches **24** from each other.

Each plasma switch **24** is capable of transforming the respective inert gas volume **40** into plasma, which is an ionized gas consisting of positive ions and free electrons, and is one of the four fundamental states of matter. Like a gas, a plasma does not have a definite shape or volume. However, unlike a gas, a plasma is electrically conductive. A plasma can be created by heating a gas to a high temperature or by subjecting a gas to a strong electric field.

The power supply **28** is electrically coupled between the electrodes **42** of each respective plasma switch **24** via insulated wires (not shown) incorporated into the respective top and bottom dielectric walls **44***a*, **44***b*. Under control of the control circuitry **30**, the power supply **28** is capable of supplying a voltage potential between the electrodes **42** of each respective plasma switch **24** to ignite the respective inert gas volume **40** into a plasma field **48**, and terminating the supply of the voltage potential between the electrodes **42** to extinguish the plasma field **48**. Thus, the plasma switch **24** operates like a virtual "door" within the respective antenna feed element **22** in that the energized plasma field **48** generates a virtual wall that blocks the RF energy through the plasma switch **24** between the respective antenna feed element **22** and the RF combiner **26** (thereby deactivating that antenna feed element **22**), and the lack of the energized plasma field **48** generates a window that allows the RF signal to seamlessly pass through the plasma switch **24** between the respective antenna feed element **22** and the RF combiner **26** (thereby activating that antenna feed element **22**). In some embodiments, instead of completely blocking the RF signal propagating within the antenna feed element **22**, the plasma field **48** may attenuate the RF energy propagating through the antenna feed element **22** to the RF combiner **26**.

Notably, a plasma is defined by three parameters, which must meet three conditions. First, a plasma has a Debye length over which an imposed electric field can be neutralized, defined as

$$\lambda_D\left(\frac{\varepsilon_0 k T_e}{n_0 e^2}\right)^{\frac{1}{2}},$$

where ε_0 is the vacuum permittivity, k is the Boltzmann constant, T_e is the electron temperature, n_0 is the plasma density, and e is the elementary charge. A plasma requires that $\lambda_D \ll L$, where L is the physical extent of the plasma. Therefore, the physical extent of the plasma must be many times greater than the Debye length so that it can "screen" an imposed electric field. Second, a plasma has a plasma parameter that is the number of electrons contained with the Debye length λ_D, defined as $\Lambda = 4/3\pi\lambda_D^3 n_0$. A plasma requires that $\Lambda \gg 1$, such that there are many free electrons in the plasma. Third, a plasma has a plasma frequency that is the frequency of the oscillations of the electron density, defined as

$$\omega_{pe} = \left(\frac{n_0 e^2}{\epsilon_0 m_e}\right)^{\frac{1}{2}},$$

where m_e is the electron mass. A plasma requires that $\omega_{pe}\tau \gg 1$, where τ is the electron collision time, requiring that the natural oscillations of the plasma occur at the plasma frequency.

In one embodiment, the power supply **28** is an RF power supply **28** having a typical RF frequency, such as, e.g., 900 MHz, 2.4 GHz, and 13.56 GHz, although the power supply **28** can take the form of a typical 60 Hz power supply used for standard Neon light bulbs, or can even be DC. The voltage potential supplied to the electrodes **42** by the power supply **28** is preferably high enough, and the distance between the electrodes **42** is preferably close enough, such that the inert gas volume **40**, at given chamber pressure, will be ignited into the plasma field **48** in accordance with the three conditions for generating the plasma field **46** set forth above.

If the inert gas volumes **40** of the respective plasma switches **24** are not isolated from each other, as illustrated in FIG. **5**, the inert gas volumes **40** are preferably maintained at atmospheric pressure, and the distance between the electrodes **42** of each plasma switch **24** are preferably less than 0.2 of the distance between adjacent plasma switches **24**, thereby minimizing the possibility that the energized electrodes **42** of one plasma switch **24** will ignite the inert gas volume **40** of an adjacent plasma switch **24** into a plasma field **48**; that is, ignition of the inert gas volume **40** into the plasma field **48** will be localized to the plasma switch **24** that is energized. However, if the inert gas volumes **40** of the respective plasma switches **24** are isolated from each other via the dielectric side walls **44***c*, as illustrated in FIG. **7**, the ignition of the inert gas volume **40** into the plasma field **48** will naturally be localized to the plasma switch **24** that is energized, the distance between the electrodes **42** of each plasma switch **24** may be greater than 0.2 of the distance between adjacent plasma switches **24**. Furthermore, the inert gas volumes **40** may be maintained at a pressure substantially less than atmospheric pressure (e.g., 0.1 to 10 Torr cm), thereby enhancing ignition of the inert gas volume **40** into the respective plasma field **48** in response to the supply of the voltage potential to the respective electrodes **42**.

The switch times for the plasma switch **24** are on the order of microseconds to seconds, based on the time required to activate the plasma field **48**. Theoretically, the plasma field **48** may be activated in the time it takes to establish a standing wave for the frequency generated by the power supply **28**. Typical ionization rate constants for ionization are on the order of 10^{-12} s (10^{12} Hz) with relaxation times of 10^{-8} s (10^{8} Hz) or faster. Preferably, the operating frequency of the power supply **28** is less than the relaxation time of the plasma field **48** to conserve power.

It is desirable that the plasma field **48** have an effective permittivity ε_n, such that the desired blocking or attenuation characteristics of the plasma field **48** with respect to the RF signal propagating within the respective antenna feed element **22** are achieved. In particular, with reference to FIG. **8**, consider a plane wave that is propagating along the positive z-axis with its electric field oriented in the x-direction. This plane wave is incident on an interface separating two media (Region 1 and Region 2), each with a unique permittivity ε, permeability μ, conductivity σ. Region 1 can be considered the media within the antenna feed element **22** (e.g., air), whereas region 2 can be considered the plasma field **48** within the plasma switch **24**. To satisfy the boundary condition between Region 1 and Region 2, some of the energy from the incident wave must be reflected off the interface, as illustrated in FIG. **5**.

Two parameters that predict the amplitude of the transmitted and reflected waves can be developed. One parameter is known as the transmission coefficient

$$\hat{T} = \frac{2\hat{n}_2}{\hat{n}_1 + \hat{n}_2},$$

and the other parameter is known as the reflection coefficient

$$\hat{\Gamma} = \frac{\hat{n}_2 - \hat{n}_1}{\hat{n}_1 + \hat{n}_2},$$

where $\hat{n}$ is the wave impedance based on the properties of the medium, given by

$$\hat{n} = \sqrt{\frac{\mu}{\varepsilon - j\frac{\sigma}{2\pi f}}}.$$

The reflection and transmission coefficients are related by $1+\hat{\Gamma}=\hat{T}$, with $-1\leq\hat{\Gamma}\leq 0$ and $0\leq\hat{T}\leq 1$. For total reflection of an interface, $\hat{\Gamma}=-1$, causing $\hat{T}=0$, and for no reflection, $\hat{\Gamma}=0$, causing $\hat{T}=1$.

Thus, it can be appreciated that the plasma field **48** must provide a reflection coefficient at the interface of 1 for total blocking of the RF signal, and a reflection coefficient greater than 0, but less than 1, for attenuation of the RF signal. Associated with a plasma is an effective permittivity ε_n equal to:

$$\frac{\varepsilon}{\varepsilon_0} = 1 - \frac{\left(\frac{\omega_{pe}}{\omega}\right)^2}{1+\left(\frac{\gamma}{\omega}\right)^2} - j\frac{\left(\frac{\omega_{pe}}{\omega}\right)^2\left(\frac{\gamma}{\omega}\right)}{1+\left(\frac{\gamma}{\omega}\right)^2},$$

$$\text{where } \omega = 2\pi f \text{ and } \omega_{pe} = \frac{n_e^2}{m_e\varepsilon_0}.$$

Thus, the effective permittivity ε_n of plasma is controlled by the collision frequency γ, plasma frequency ω_{pe}, and electron number density n_e. For a specified signal frequency f, there corresponds a critical electron density n_{ec} for which $\omega_p=\omega$. The plasma is "underdense" when the plasma density $n_e<n_{ec}$, and "overdense" when $n_e>n_{ec}$. An overdense medium has a reflective constant of unity, so that the RF signal is completely blocked, and none of the RF signal is transmitted through the plasma field **48**. An underdense medium can still provide attenuation to an RF signal (the attenuation increasing with the density of the plasma) by reflecting a portion of the incident RF signal. As a general rule, if the frequency of the RF signal is less than the resonant frequency of the plasma field **48**, the RF signal will be blocked by the plasma switch **24**, and if the frequency of the RF signal is greater than the resonant frequency of the plasma field **48**, the RF signal will pass through the plasma switch **24**.

The plasma density of the plasma field **48** will generally dictate the blocking or attenuating characteristics of the plasma switch **24** with respect to the RF energy propagating through the respective antenna feed element **22**. For example, for RF energy having a frequency of several GHz, as a general rule, a plasma field **48** having a plasma density greater than 10^9 free electrons per cm^3 will completely block RF energy incident on the plasma field **48**, whereas a plasma field **48** having a plasma density in the range of 10^7-**10^9** free electrons per cm^3 will attenuate, at varying degrees, RF energy incident on the plasma field **48**.

For the purposes of this specification, RF energy is blocked if less than ten percent of the RF energy passes through the plasma switch **24**; however, it is preferred that less than one percent of the RF energy passes through the plasma switch **24** when the RF energy is blocked. The voltage applied to the electrodes **42** by the power supply **28** and the distance between the electrodes **42** can be selected to provide the desired blocking or attenuation (at various attenuation levels) of the RF energy of a given frequency through the plasma switch **24**. The level of the voltage applied to the electrodes **42** by the power supply **28** to completely block the RF energy will generally be higher than the voltage applied to the electrodes **42** by the power supply **28** to attenuate the RF energy. By the same token, the greater the level of voltage applied to the electrodes **42** by the power supply **28**, the greater the RF energy will be attenuated (if not otherwise completely blocked). For attenuation, several different voltage levels and corresponding attenuation levels may be stored in memory, such that the control circuitry **30**, for any desired attenuation level for an antenna feed element **22**, the control circuitry **30** may retrieve the corresponding voltage level from memory, and command the power supply **28** to deliver that that corresponding voltage level to the electrodes **42** of the plasma switch **24** corresponding to that antenna feed element **22**.

Having described the arrangement, structure, and function of the reconfigurable antenna **10**, one method **100** of operating the reconfigurable antenna **10** will now be described with respect to FIG. **9**. First, the antenna **10** is operated in the transmit mode or receive mode (step **102**). Next, a subset of the antenna feed elements **22** is selected (step **104**). In the illustrated embodiment, the subset of antenna feed elements **22** is selected by the control circuitry **30**. The subset of the antenna feed elements **22** may comprise, e.g., only a single antenna feed element, or may comprise multiple antenna feed elements. Then, RF energy is conveyed between the spherical dielectric lens **20** and the RF combiner **26** in accordance with the transmit mode or the receive mode (step **106**). That is, in the receive mode, the RF energy is received from the object of interest **38***a* at the spherical dielectric lens **20**, and in the transmit mode, the RF energy is transmitted from the spherical dielectric lens **20** to an object of interest **38***b*.

Then, the plasma switches **24** are independently operated to generate at least one RF beam **36** having a characteristic (e.g., a directional angle, an aperture, or a group size of the RF beam(s) **36**). In particular, the subset of the antenna feed elements **22** is activated by not energizing the corresponding plasma switches **24**, thereby passing the RF energy through the corresponding subset of the plasma switches **24** (step **108**), and the remaining ones of the antenna feed elements are deactivated by energizing the corresponding plasma switches **24**, thereby blocking the RF energy through the corresponding remaining ones of the plasma switches **24** (step **110**).

In the illustrated embodiment, the control circuitry **30** activates the subset of plasma switches **24** by commanding the power supply **28** to not apply voltage across each pair of electrodes **42** of the subset of plasma switches **24**. As a result, an electric field is not applied across each inert gas volume **40** of the subset of the plasma switches **24**, such that the inert gas volume **40** is not ignited into a plasma field **46**, thereby passing the RF energy through the subset of plasma switches **24**. In contrast, the control circuitry **30** deactivates the remaining plasma switches **24** by commanding the power supply **28** to apply voltage across each pair of electrodes **42** of the remaining plasma switches **24**. As a result, an electric field is applied across each inert gas volume **40** of the remaining plasma switches **24**, such that the inert gas volume **40** is ignited into a plasma field **46**, thereby blocking the RF energy through the remaining plasma switches **24**.

Next, a different subset of the antenna feed elements **22** is selected (step **112**), and the plasma switches **24** are independently operated again at steps **108** and **110** to modify the characteristic of the RF beam(s) **36**. Steps **108** and **110** can be repeated to continually modify the characteristic of the RF beam(s) **36** as many times as desired.

Another method **200** of operating the reconfigurable antenna **10** to geolocate an object of interest **38***a* will now be described with respect to FIG. **10**. First, the antenna **10** is operated in the receive mode (step **202**). Next, a subset of the antenna feed elements **22** is selected (step **204**). In the illustrated embodiment, the subset of antenna feed elements **22** is selected by the control circuitry **30**. For detailed geolocation of the object of interest **38***a*, the subset of the antenna feed elements **22** preferably includes only a single antenna feed element (e.g., if the object of interest **38***a* is to be located in a very small area of the sky), although in alternative embodiments, the subset of antenna feed elements **22** may comprise multiple antenna feed elements (e.g., if the object of interest **38***a* is to be located in large area of the sky). Then, RF energy is received from the object of interest **38***a* at the spherical dielectric lens **20** (step **206**).

Then, the plasma switches **24** are independently operated to generate an RF beam **36***a* having a directional angle from the focusing element **20** is generated. In particular, the subset of the antenna feed elements is activated by not energizing the corresponding plasma switches **24**, thereby passing the RF energy from the subset of antenna feed elements **22** to the RF combiner **26** (step **208**), and the remaining ones of the antenna feed elements are deactivated by energizing the corresponding plasma switches **24**, thereby blocking the RF energy from the antenna feed elements **22** to the RF combiner **26** (step **210**).

In the illustrated embodiment, the control circuitry **30** activates the subset of plasma switches **24** by commanding the power supply **28** to not apply voltage across each pair of electrodes **42** of the subset of plasma switches **24**. As a result, an electric field is not applied across each inert gas volume **40** of the subset of the plasma switches **24**, such that the inert gas volume **40** is not ignited into a plasma field **46**, thereby passing the RF energy through the subset of plasma switches **24**. In contrast, the control circuitry **30** deactivates the remaining plasma switches **24** by commanding the power supply **28** to apply voltage across each pair of electrodes **42** of the remaining plasma switches **24**. As a result, an electric field is applied across each inert gas volume **40** of the remaining plasma switches **24**, such that the inert gas volume **40** is ignited into a plasma field **46**, thereby blocking the RF energy through the remaining plasma switches **24**.

Next, the signal strength of the RF energy output by the RF combiner **26** is measured, e.g., by the transceiver **12** (step **212**). Then, it is determined whether or not all possible subsets of antenna feed elements **22** have been selected for activation (step **214**). If not, different subsets of the antenna feed elements **22** are selected (step **216**), and the plasma switches **24** are independently operated again at steps **208** and **210** to modify directional angle of the RF beam **36***a* and the RF energy output by the RF combiner **26** is measured at step **212**.

If all the possible subsets of antenna feed elements **22** have been determined to be selected for activation at step **214**, the object of interest **38***a* is geolocated based on the measured signal strength corresponding to at least one of the selected subsets of antenna feed elements **22**, e.g., by the control circuitry **30**. In particular, at least one subset of antenna feed elements **22** corresponding to at least one of the highest measured signal strengths is determined (step **218**), the directional angle of the RF beam **36***a* is correlated to each of these subset(s) of antenna feed elements **22** (step **220**), and the object of interest **38***a* is geolocated based on the correlated directional angle(s) of the RF beam **36***a*. Correlation can be accomplished, e.g., by storing in memory directional angles corresponding to the respective subsets of the antenna feed elements **22**, and retrieving the directional angle corresponding to the subset(s) of antenna feed elements **22** corresponding to the highest measured signal strength(s).

In one embodiment, only one subset of antenna feed elements **22** corresponding to the highest measured signal strength is determined, in which case, the directional angle of the RF beam **36***a* can be correlated to only this subset of antenna feed elements **22**, and the object of interest **38***a* is geolocated by identifying the directional angle of the RF beam **36***a* as the location of the object of interest **38***a*. In another embodiment, multiple subsets of antenna feed elements **22** corresponding to the highest measured signal strengths are determined, in which case, the directional angles of the RF beam **36***a* are correlated to the multiple subsets of antenna feed elements **22**, and the object of interest **38***a* is geolocated by computing an interpolated directional angle from the directional angles of the RF beam **36***a* based on the corresponding highest measured signal strengths, and identifying the interpolated angle of the RF beam **36***a* as the location of the object of interest **38***a*. For example, the directional angles can be weighted in accordance with the measured signal strengths corresponding to the multiple subsets of antenna feed elements **22**, and then averaged to obtain the interpolated directional angle.

Although certain illustrative embodiments and methods have been disclosed herein, it can be apparent from the foregoing disclosure to those skilled in the art that variations and modifications of such embodiments and methods can be made without departing from the true spirit and scope of the art disclosed. Many other examples of the art disclosed exist, each differing from others in matters of detail only. Accordingly, it is intended that the art disclosed shall be limited only to the extent required by the appended claims and the rules and principles of applicable law.

We claim:

1. A reconfigurable antenna, comprising:

a plurality of antenna feed elements;

a plurality of plasma switches respectively associated with the antenna feed elements,

wherein each of the plasma switches comprises a volume of inert gas and a pair of electrodes spanning the respective inert gas volume; and

control circuitry for independently operating the plasma switches to selectively activate and deactivate the antenna feed elements.

2. The reconfigurable antenna of claim **1**, further comprising a focusing element having a focal plane on which the antenna feed elements are located.

3. The reconfigurable antenna of claim **2**, wherein the focusing element is a dielectric lens.

4. The reconfigurable antenna of claim **3**, wherein the dielectric lens is a spherical dielectric lens.

5. The reconfigurable antenna of claim **1**, further comprising a dielectric chamber containing the inert gas volumes.

6. The reconfigurable antenna of claim **1**, wherein the control circuitry is for independently operating the plasma switches to attenuate the antenna feed elements.

7. The reconfigurable antenna of claim **1**, further comprising a radio frequency (RF) combiner coupled to the antenna feed elements via the respective plasma switches.

8. The reconfigurable antenna of claim **1**, further comprising a power supply for supplying a voltage to the pair of electrodes of each of the plasma switches sufficient to ignite the respective inert gas volume into a plasma field.

9. The reconfigurable antenna of claim **8**, wherein the control circuitry is for selectively controlling the supply of the voltage from the power supply to the respective plasma switches to selectively turn the respective antenna feed elements on or off.

10. The reconfigurable antenna of claim **1**, wherein the control circuitry is for independently operating the plasma switches to dynamically steer an RF beam.

11. The reconfigurable antenna of claim **10**, wherein the control circuitry is for independently operating the plasma switches to selectively activate and then deactivate the respective antenna feed elements one at a time.

12. An antenna, comprising:

at least one antenna feed element;

at least one plasma switch respectively associated with the at least one antenna feed element, wherein each of the at least one plasma switch comprises a volume of inert gas, and a pair of electrodes spanning the respective volume of inert gas; and

a power supply for supplying a voltage to the pair of electrodes of each of the at least one plasma switch sufficient to ignite the respective inert gas volume into a plasma field.

13. The antenna of claim **12**, further comprising a focusing element having a focal plane on which the antenna feed element is located.

14. The antenna of claim **13**, wherein the focusing element is a dielectric lens.

15. The antenna of claim **14**, wherein the dielectric lens is a spherical dielectric lens.

16. The antenna of claim **12**, wherein the plasma field is capable of deactivating the respective antenna feed element.

17. The antenna of claim **12**, wherein the plasma field is capable of attenuating the respective antenna feed element.

18. The antenna of claim **12**, wherein the at least one antenna feed element comprises a plurality of antenna feed elements, and the at least one plasma switch comprises a plurality of plasma switches.

19. The antenna of claim **18**, further comprising a radio frequency (RF) combiner coupled to the antenna feed elements.

20. A method of operating an antenna comprising a focusing element having a focal plane, a plurality of antenna feed elements located on the focal plane, a plurality of plasma switches respectively associated with the antenna feed elements, and a radio frequency (RF) combiner coupled to the antenna feed elements via the plasma switches, the method comprising:

(a) conveying RF energy between the focusing element and the RF combiner;

(b) selecting a subset of the antenna feed elements;

(c) independently operating the plasma switches to activate the subset of the antenna feed elements, thereby passing the RF energy through the corresponding subset of the plasma switches, and to deactivate remaining ones of the antenna feed elements, thereby blocking the RF energy through the corresponding remaining ones of the plasma switches, such that the antenna generates at least one RF beam having a characteristic;

(d) selecting a different subset of the antenna feed elements;

(e) repeating step (c) with the different subset of antenna feed elements, such that the characteristic of the at least one RF beam is modified.

21. The method of claim **20**, wherein the characteristic of the at least one RF beam is a directional angle of the at least one RF beam.

22. The method of claim **20**, wherein the characteristic of the at least one RF beam is an aperture of the at least one RF beam.

23. The method of claim **20**, wherein the characteristic of the at least one RF beam is a group size of the at least one RF beam.

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